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THE DESIGN, CONSTRUCTION, AND CALIBRATION OF A SPECTRAL, PROJECTION, TRANSMISSION, THREE-COMPONENT, SUBTRACTIVE COLOR DENSITOMETER HEAD

by
H. Nick Morgan

A thesis submitted in partial fulfillment of the
requirements for the degree of Bachelor of Science
in the Department of Photographic Science and Instrumentation
in the School of Photographic Arts and Sciences in
the College of Graphic Arts and Photography
of the Rochester Institute of Technology

June, 1970

ACKNOWLEDGMENTS

Acknowledgment and many thanks are expressed to Mr. Richard Norman, whose patience and talent was much appreciated during the machining of several parts that were necessary to my project.

ABSTRACT

In the field of densitometry, there is a current trend to create standards which are more specific, more technical, and more practical than the standards which have been produced in the past. This paper deals with the design, construction, and evaluation of an instrument which conforms to one of these standards. A bit more was added, in that the instrument was made to be used with negative color materials.

The instrument constructed was a spectral, projection, transmission, three-component, subtractive color densitometer head. One of the unique characteristics of the instrument is the fact that a spectral lamp was used for the light source. This gave evaluating wavelengths that were quite narrow. The instrument measured a new type of density called 'projected density'. The term being derived from the geometric conditions specified in the standard. The geometry specified is similar to that one might find in a micro-film reader.

For samples that were measured on the new instrument and on a conventional instrument, densities were found to be higher on the new instrument, due probably to a narrower collection angle.

Specifications are given for building a prototype instrument.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

This paper will deal with the applications of three disciplines—photometry, optics, and electronics—with regard to the problems of designing, building, and calibrating a three-component spectral projection transmission color densitometer. This project was planned to be executed in the way it might be executed in industry, rather than as a pure research experiment. In other words, it is an engineering type of project rather than a scientific type of problem.

The problems associated with this type of project are many of the same as with other types of research—limited time, limited components and apparatus, and limited funds. There are also the additional problems of the testing of each component of the system to insure that it is functioning correctly and to chose components that are complementary to one another. Where this type of project is different is in its outcome—the project is usually either a success or a failure; it either works or it doesn't work.

The aim of this project was primarily to build an instrument that worked correctly. After this primary was accomplished, there were several others of lesser immediacy, but still of great interest, namely;

a.) the stability of the instrument(the precision obtainable and the frequency with which the instrument needs to be recalibrated.)

b.) the sensitivity (the range of the instrument.)

c.) the ease of operation (to be considered in the designing process and evaluated subjectively after construction.)

d.) the speed and accuracy (how other machines compare to it.)[1]

The reasons why this author is interested in this problem are several in nature. First of all, is his interest in instrumentation as opposed to chemistry of the photographic system. A second reason is that this type of work is what the author now believes he would find satisfaction in. It is in this regard that the engineering type of approach was chosen. The problem is one of a practical nature which would seem to have great value in direct future endeavors. This is why this particular problem was chosen.

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[1]Ralph M. Evans, W.T. Hanson, W. Lyle Brewer, Principles of Color Photography, (New York, 1953), p. 415.

SYSTEM DESIGN

In this section of the paper, the various constraints and conditions placed on the system by one reason or another will be presented and discussed. Toward the end of this section reasons will be given as to why certain descisions were made as to the elements of design so that the logic of those descisions will be evident.

Geometric Conditions

There have been (and are) standards that have dealt with various types of density measurement. The most common of these are usually referred to as 'diffuse' or 'specular' density, depending, of course, on their respective geometrical conditions. Due to these specified conditions in the standards, they may be regarded as extreme cases and are never completely fulfilled in a practical application.[1] It has also been found that where materials for projection are used, the above two cases were not as responsive to the systems variables as they should be (or could be). Since a variety of photographic materials are viewed by projection, (motion pictures, transparencies, microfilm, etc.). it would seem natural that a standard for projected density would exist. Until this point, none have existed.

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[1] American National Standard Terms, Symbols, and Notation for Optical Measurements, PH2.36, Seventh Draft, Oct. 23, 1969 p. 3.

A proposed standard has been drafted to fill this need. This standard is designated, "PH2-28/27 American National Standards Conditions for Transmission Measurements Pertaining to Projection (Optical Density)". A copy of this standard may be found under Appendix A.

The conditions in the standard have been determined to simulate the conditions that occur in a projection type of system using condensers.[1] In this type of system only the flux which is projected from the sample by the projection lens is considered. As this projected flux is dependent upon the cone angle subtended by the projection lens, the cone angle is one of geometric conditions specified in the standard. Two angles are specified, one having a half-angle of 6.3° and the other having a half-angle of 17.3°. For convenience, these are usually expressed in terms of f-numbers, the former corresponding to f/4.5 and the latter to f/1.6.

Conditions are also specified for the sampling aperture, namely that the sampling aperature should be uniformly illuminated and that the diameter of the aperature be no greater than one-tenth the diameter of the projecting or illuminating lens. The uniformity of the illumination is to be determined by scanning the sampling aperature with a photometer of the type having an acceptance angle of at least 20°. The flux measured at any place on the aperature should be within 10% of the maximum value.

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[1] American National Standard Conditions for Transmission Measurements Pertaining to Projection, PH2-28/27, Nov.,1969 p. 1.

Spectral Conditions

The most common measure of photographic effect is, of course, density. This term is defined in many references and will not be gone into here, except to state that for black and white materials density is a measure of the modulation of the sample.[1] Normally these measurements are made independent of spectral conditions since the assumption is made that the materials are neutral.

The above is the case with the aforementioned standard. The spectral conditons for it are based on a tungsten lamp operated at a color temperature of 3000K. This is completely acceptable for use with black and white materials.

Color materials, on the other hand are quite different and cannot be evaluated in this manner. Most modern color films are composed of three layers, each layer being sensitized by a different dye. It is not only necessary to measure the modulation of the sample, but it is also necssary to measure the effect of the three components which make up the sample. The proposed standard does not do this, as it is a standard pertaining to black and white materials.

It seems reasonable to assume that if a standard for projected density is useful for black and white materials, it will be equally as useful (or even more so) for color materials. No standard of this type exists. Rather than starting from a begining, it would seem more reasonable to

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[1]W.S. Shoemaker, H.N. Todd, Fundamentals of Photographic Science, (Rochester,N.Y., 1966), p. III-8.

use the spectral conditions of previous standards and combine them with the geometric conditions of the current proposed standard. This is what has been done, the result being a unique standard embracing reasonable and plausible constraints.

In previous standards, the measurement of the three components of the sample have been made by employing three different spectral conditions. If these three different spectral conditions consist of narrow bandwidths of energy which are close to the maximum absoptions of the components, the measurements will show the effect of small variations in the components. (See Figure 1)[1]

In the soon to be (or now) obsolete standard for color density, (USASI PH2.1), three different spectral lines (435.8, 546.1, 643.8) were specified as the light sources to be used for the radiant flux.[2] Because this is a difficult standard to reproduce, a less strenuous standard was/is employed which allows for one light source to be used with appropriate filters to produce a fairly narrow bandwidth. This is the standard that is used in virtually all commercial operations. For the standard to be employed, though, it is necessary that a spectral source instrument be available for comparison at some time. For this reason, it was decided that the spectral source type of instrument would be built.

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[1] USASI Standard for Spectral Diffuse Densities of Three-Component Subtractive Color Films, PH 2.1, p. 7.

[2] Ibid., p. 6.

Spectral Density versus Wavelength Relationships
for a Typical Three-Component Monopack Film.

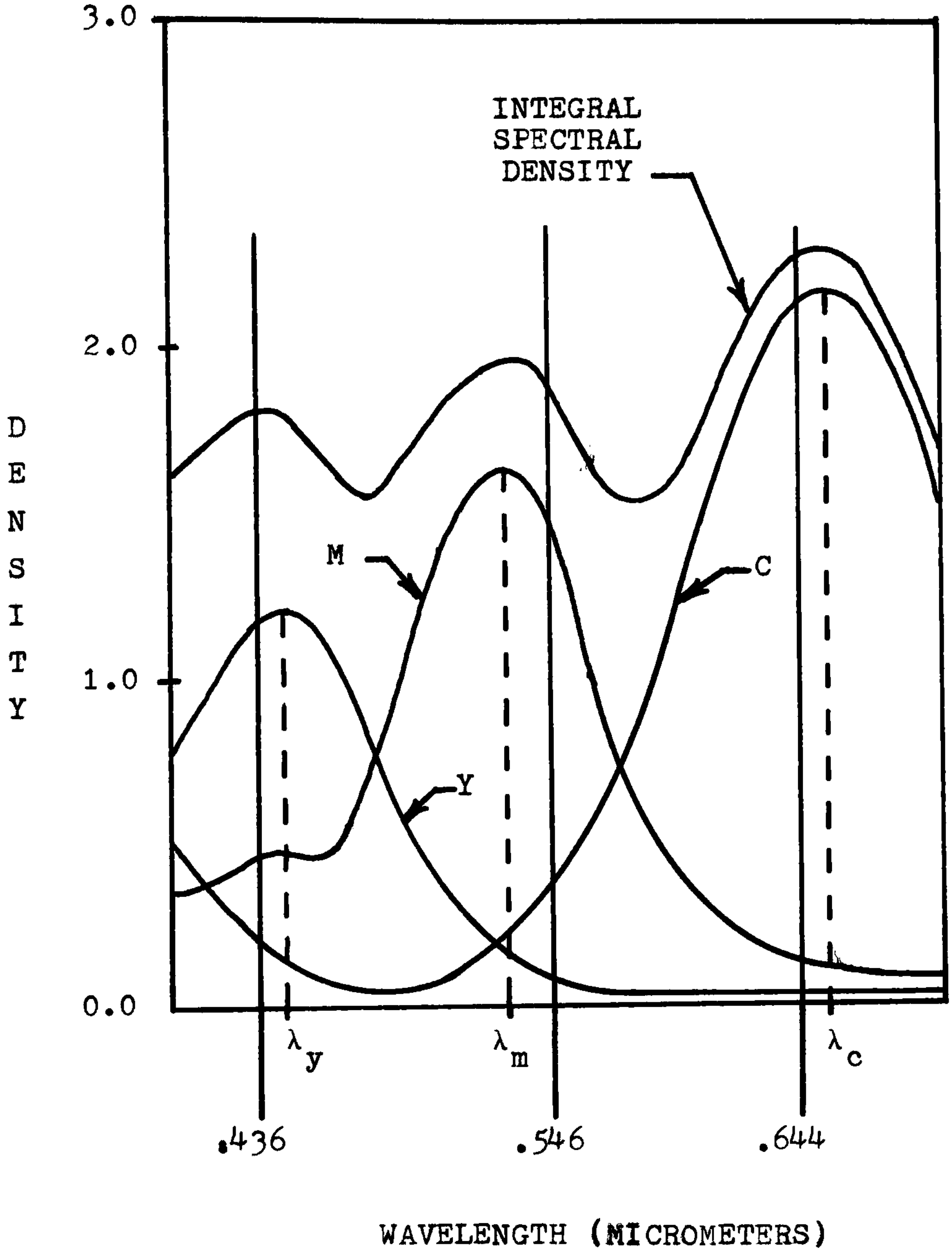

FIGURE 1

Other Constraints

Another constraint to be considered in the designing of this instrument is its size. Since it was to be mounted and enclosed in a chassis, it would be necessary to take into account the length of the potical path in order to keep its length reasonable. While keeping this length reasonable, it is also important to consider the heat given off by the lamp and to keep any working surfaces and the sample itself at a sufficient distance that they will not be destroyed by heat and that any operator is not harmed.

Although several circuits are designed and available in the literature for use in the readout portion of the densitometer, the descision was made that a great deal of time and money would be saved if the electronics of a current densitometer were used.[1] Although a visual densitometer would probably be much simpler to build, it was decided that an electronic unit be built, since that seems to be the contemporary trend and also to make the instrument visually independent with respect to the operator.

The optical components were another part of the system that required careful design. As it turned out, lenses that were available were used, and ray traces were run in order to insure that these lenses would be suitable for use.

Due to limited avaiability of equipment and in order to keep the cost down, several components, as above, were chosen

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[1]M.H. Sweet, "Logarithmic Photometer", Electronics, 19:105-109, (Nov. 1946).

to be used that ordinarily would not be used. The lenses used for the projecting and illuminating lenses were motion picture lenses. The condensing lens was a slide projector lens.

SYSTEM CONSTRUCTION

The system was built and tested on an optical bench for its primary tests. It is better to make some first rough tests to determine if the instrument will work at all rather than spending a lot of time building some sort of elaborate piece of apparatus and then finding that it will not work. The rest of this section will deal with each component of the system individually.

Light Source

The first two required wavelengths (435.8, 546.1) happen to be two of the spectral lines of Mercury; the third (643.8) happens to be a spectral line of Cadmium. In order to obtain these three wavelengths, it is obviously necessary to have a lamp that produces them. A combined Mercury-Cadmium vapor lamp is of such a type. The combining of the Mercury and Cadmium eliminates the necessity of having two lamps and also alleviates the problem of changing the optical system from one lamp to another.

Since a Phillips lamp power supply was available, a lamp of Phillips manufacture was purchased. This lamp was a combined Mercury-Cadmium-Zinc type. In order to use the lamp for the system at each wavelength, it was necessary to filter out the unused spectral lines. Since the lines are quite far apart, this is a fairly simple matter. There was some concern at the beginning of the project as to whether or not the lamp would produce sufficient radiation in the red region as to be enough to excite the photomultiplier tube, as they are notoriously low in response in the 600-700 (micrometers) region. This will be discussed later.

Since the lamp puts out a great deal of power in the ultraviolet region, it was necessary to fabricate a lamphouse for it as it is dangerous to look at directly. The lamp gets quite hot, therefore, local ventilation is necessary. Warm-up time is about ten minutes, after which the lamp maintains stability and provides quite an evenly illuminated area in the center of the vapor area. Upon receipt of the lamp, it was aged for a time to insure stability. A photometer was employed to determine the amount of drop in output observed. The amount of loss was undetectable. The lamp was also viewed through a monochrometer to determine if the spectral lines were where they should be. The lines were observed in place and the lamp was assumed to be operating correctly.

FILTERS

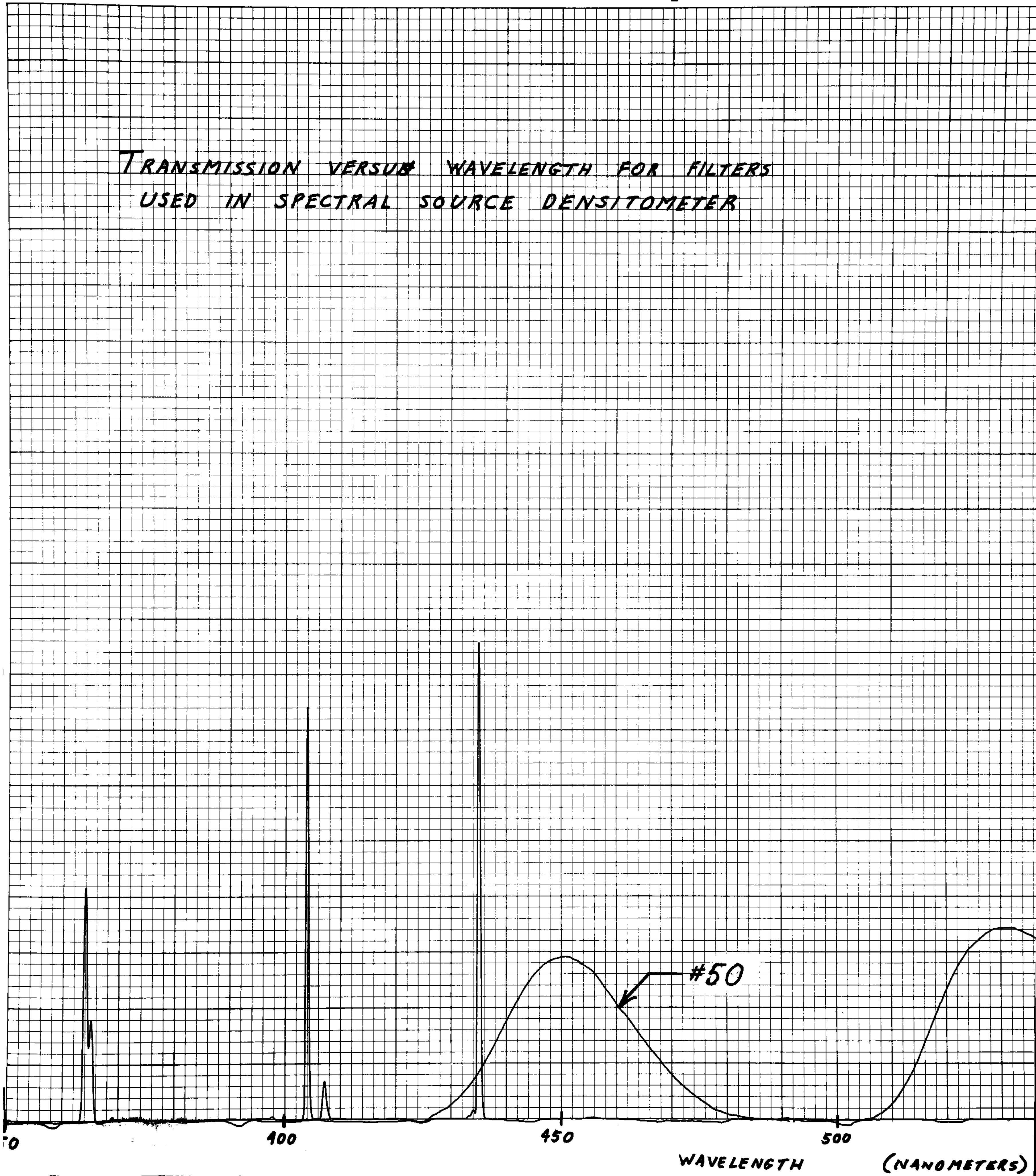
The main function of the filters is to block out the other spectral lines of the light source so that only one line is transmitted. This essentially produces light of one wavelength, one micrometer wide (this depends upon the quality of the lamp). In any event, the bandwidth of light transmitted is much narrower with a spectral source than with a tungsten source and filters.

Many combinations of filters were tried and for one reason or another were eliminated. The two combinations of filters that appeared to be the most desirable were Wratten #92, #93, and #94 and the set of Wratten #29, #50, and #74. The transmission characteristics of these two sets may be compared in figures two and three. (pages 13 & 14)

The former set of filters (92,93,94) are the set that are used in most commercial color densitometers. This might seem to be good credentials for using them in the current project. For several reasons, the latter set was used (29,50,74). The bandwidths for the blue are about the same for both the #50 and the #94, but the #50 has a slightly higher transmission then the #94 and the # 50 still blocks out the 404 Mercury line. (The spikes on the graphs are Mercury lines used for calibration purposes.) The same case is again true for the green filters—both have about the same bandwidth, but the #74 transmits quite a bit more energy than the #93. The most obvious case is the red. The #92 transmits about 72% of the energy while the #29 transmits about 86% of the energy incident on it. Later results found this extra energy quite important.

Optics

After several possible optical configurations, one was decided on that made use of a minimum number of elements. For the most part, the optical configurations were specified in the standard under geometric conditions. (See page 3) The only other problems have to do with focal length, magnification, and stop position. There were two sets of lenses


TRANSMISSION VERSUS WAVELENGTH FOR FILTERS
USED IN SPECTRAL SOURCE DENSITOMETER
#50
0
400
450
500
WAVELENGTH (NANOMETERS)

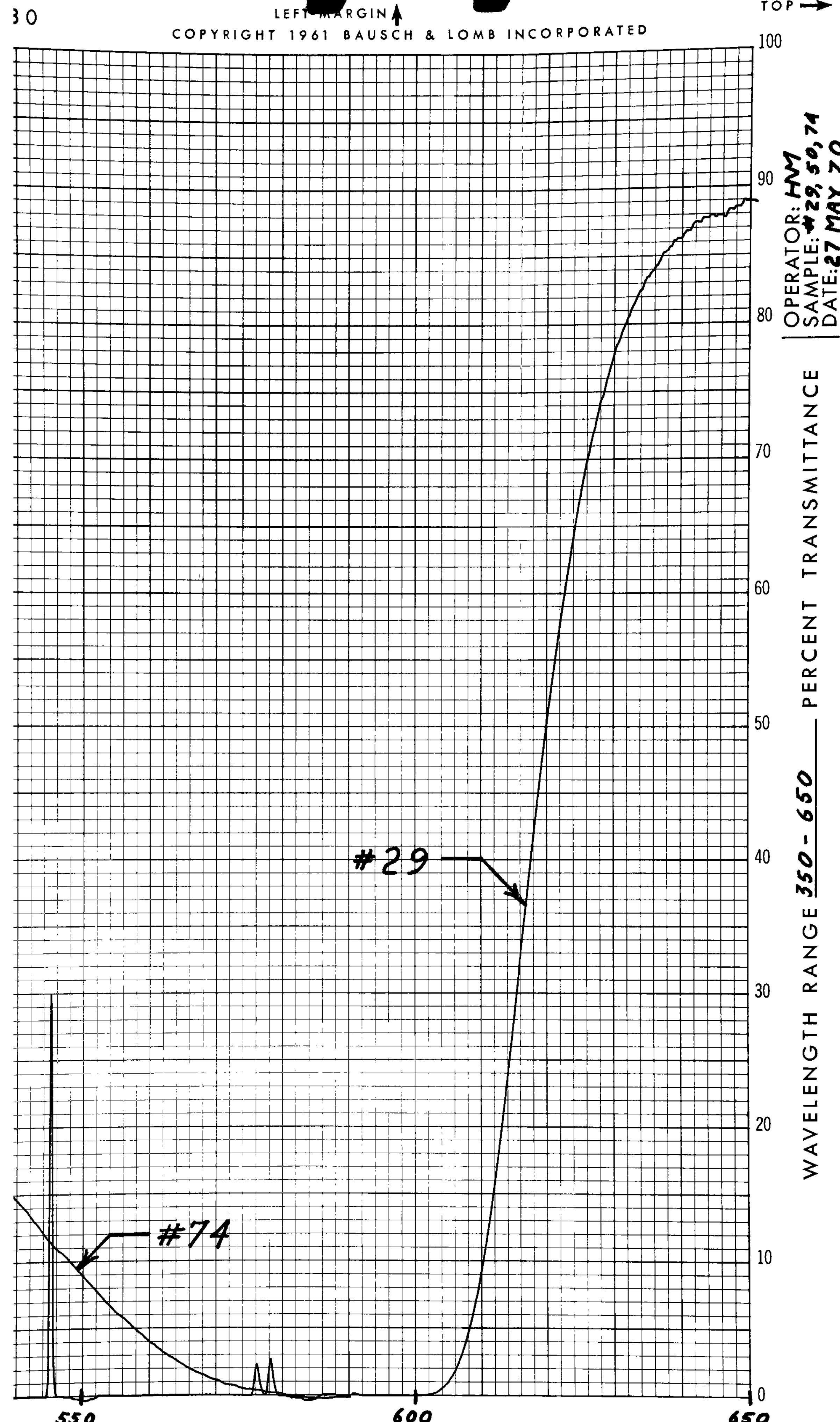
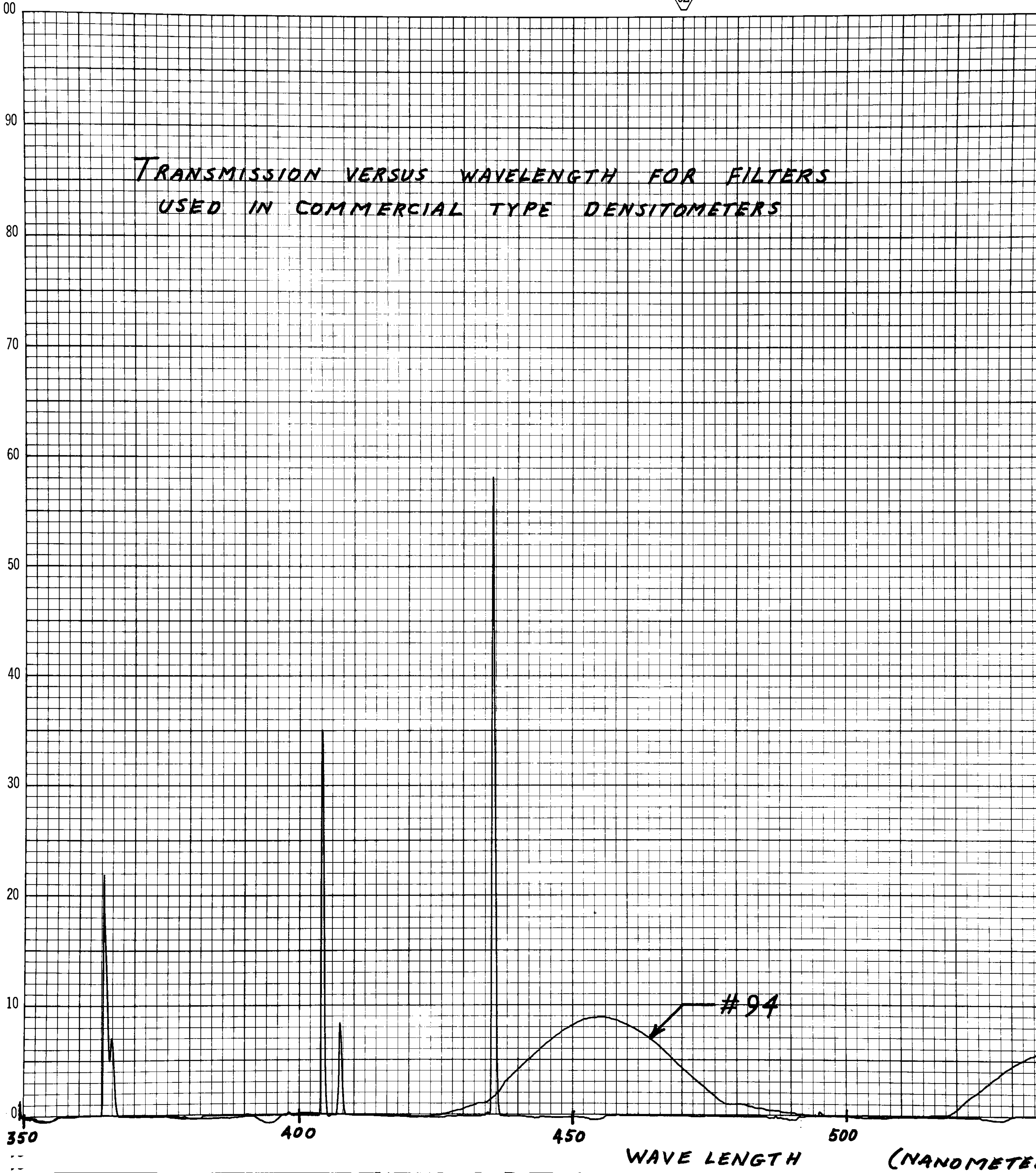
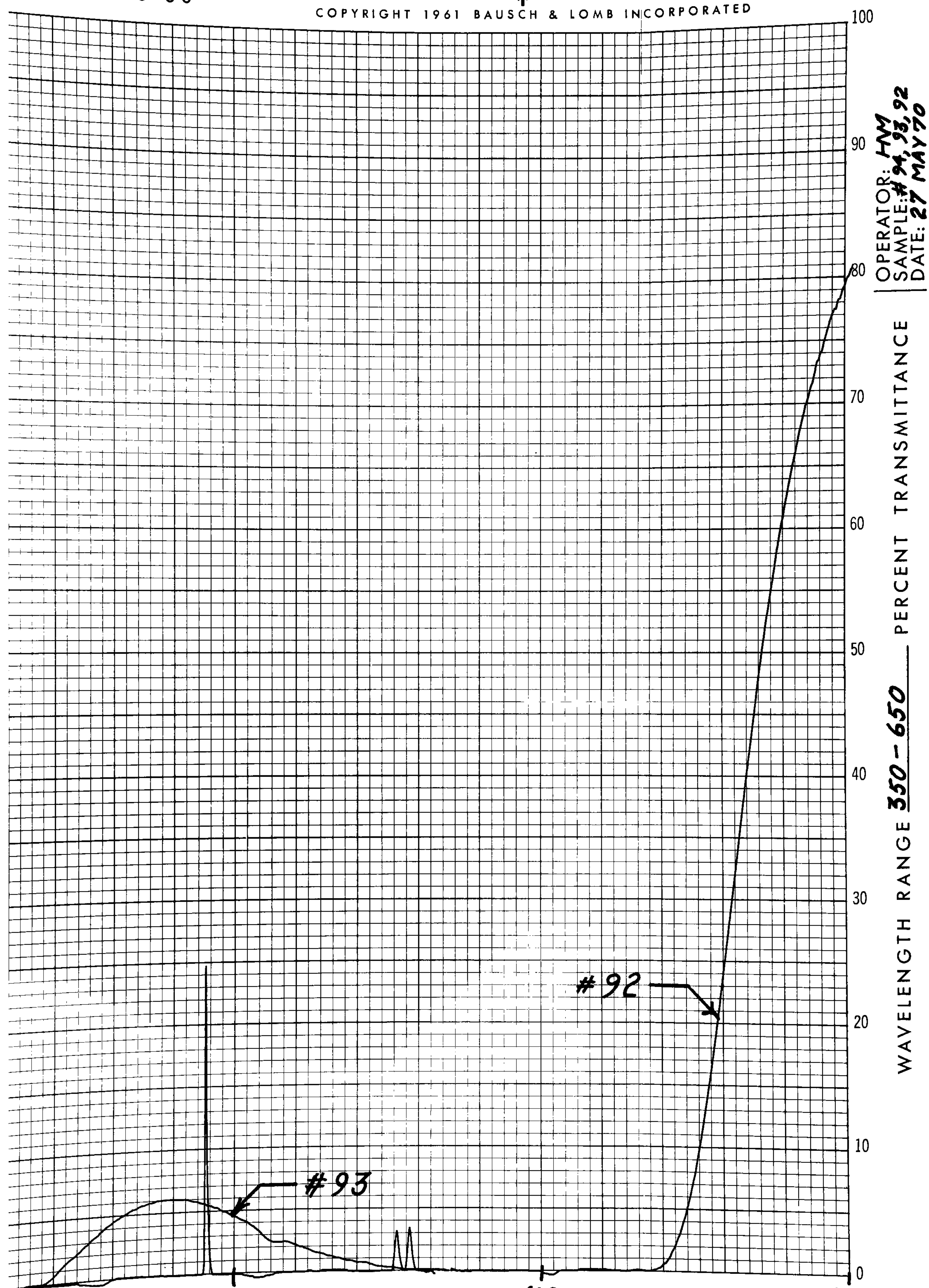

30
LEFT MARGIN
TOP
COPYRIGHT 1961 BAUSCH & LOMB INCORPORATED
100
90
80
70
60
50
40
30
20
10
0
550
600
650
#29
#74
OPERATOR: HM
SAMPLE: #29, 50, 74
DATE: 27 MAY 70
PERCENT TRANSMITTANCE
WAVELENGTH RANGE 350 - 650

FIGURE 2

BAUSCH & LOMB INCORPORATED CATALOG NO. 33-2

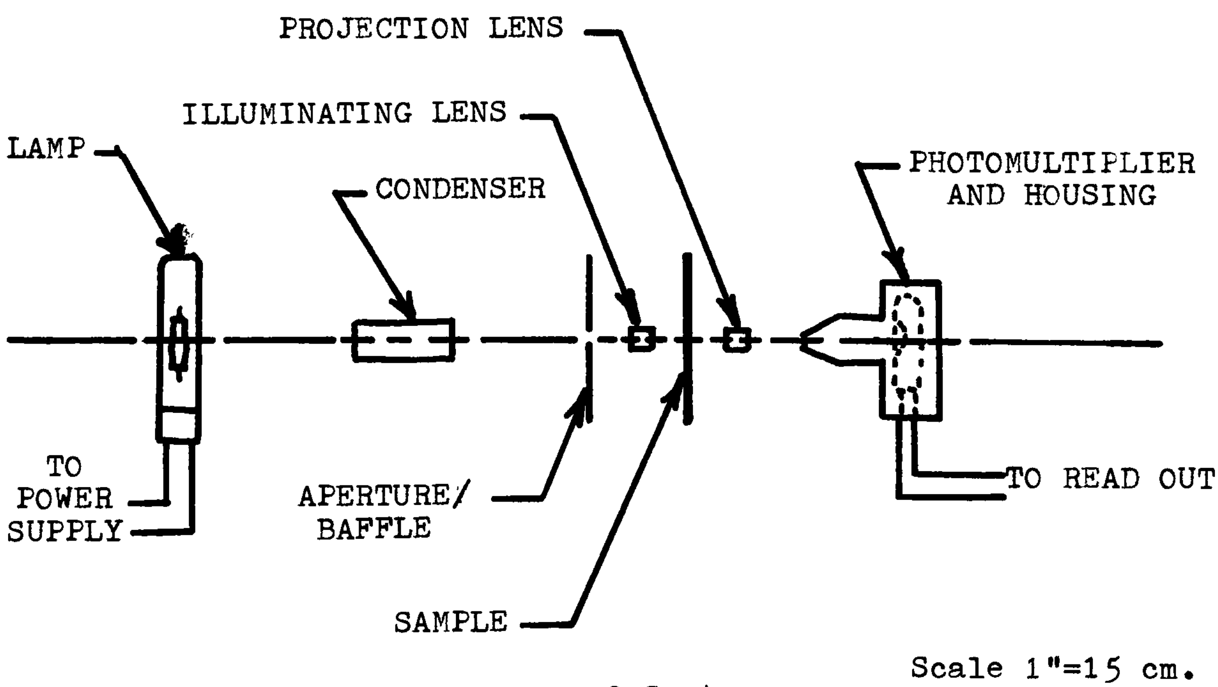




COPYRIGHT 1961 BAUSCH & LOMB INCORPORATED
100
90
80
70
60
50
40
30
20
10
0
550
600
650
#93
#92
OPERATOR: HM
SAMPLE: #94, 93, 92
DATE: 27 MAY 70
WAVELENGTH RANGE 350 - 650
PERCENT TRANSMITTANCE

FIGURE 3

available; a set of one-inch f/4.5 lenses and a set of 15 mm f/2.5 lenses. The one-inch set was originally chosen because of their larger numerical aperture. A ray trace was done on this system and it was found that the system would not fit inside of the chassis intended to be the case for the instrument. Thus, the descision to use the 15 mm lenses was made, assuming,of course, that these lenses would fit. A ray trace was run and the determination made that the lenses were suitable.[1] A condensing lens was then chosen which would place the lamp a sufficient distance away from the other components but still leaving enough roomaround the lamp for circulation. A schematic is included depicting the optical components and their placement. (See Figure 4)



<u>Schematic of System</u>

Figure 4

As far as the geometric conditions were concerned, the f/4.5 geometry was chosen (this one will recall is the condition simulating a micro film reader).

Another constraint specified by the standard was the size of the sampling aperture. It was defined as no greater than one-tenth the clear aperture of the projecting lens. The clear aperture of this lens was six millimeters, therefore, the size of the sampling aperature would be .6 millimeters. This is rather on the small side, but careful work and a small sized drill, and an aperature this size can be realized.

As advised, a one-to-one ratio of image size was maintained in order to keep in the macro range,as micro density is not what was wanted.

Readout

The electronics from a Macbeth densitometer were used. Because of their convient size, the snoot and housing for the photomultiplier were used intact. The machine was calibrated so as to respond linearly to the incident radiation on the photomultiplier. (Actually, this is linear with respect to the meter, it is actually responding logarithmicly to incident radiation.)

The system was then aligned following the previous conditions. The system was set up such that with no sample in place, a reading of close to zero density was maintained. Several samples were read and the results appear in the following section.

RESULTS AND CALCULATIONS

The samples that were read on the instrument constructed in the project were also read on a conventional diffuse transmission densitometer. It was of interest to compare them to see if they were indeed significantly different. If they were not different, there would be no point in constructing this new instrument. The comparitive results are listed in table one.

KEY A-Conventional diffuse densitometer
B-Spectral source projection densitometer

Sample #	Red		Green		Blue	
	A	B	A	B	A	B
1	.18	.21	.64	.65	.96	.99
2	.75	.81	1.07	1.10	1.26	1.36
3	.88	.97	1.21	1.26	1.37	1.48
4	1.26	1.39	1.44	1.55	1.12	1.16

Table 1

Results of Experiment

As is obvious, the projection densitometer read a higher density for all samples. In some cases the difference was quite small. As this was the case, it was decided that a statistical method be employed to determine if the difference is significant or not. The method of paired data was used.

In this method, the differences between the machines are determined, and inferences are then made based on these differences. For the test of difference, an alpha risk of 0.01 was assumed.

Using this technique, the conclusion was reached, based on the data, that the two instruments were different.

ANALYSIS, CONCLUSIONS, & SUMMATION

The most obvious conclusion that can be made, of course, is that the instrument did indeed function, in that it gave a specified output for a specified input. The meaning or usefulness of this output is another question again.

In order to determine what the output means and if it is reasonable, it is necessary to examine the results. Upon observation, one will notice that the values for projected density were slightly higher, for comparable samples, than for those measured on a diffuse type of densitometer. This means that less radiant flux was collected by the projected system than by the diffuse system. This is reasonable, since the sample would have the tendency to diffuse the incident flux and the projecting lens is only covering a half-angle of 6.3° instead of 90° for a diffuse system. This is quite sufficient reason, therefore, to assume that the results are reasonable.

One must remember that a dye image was used for the sample. Had a silver image been used, the difference would have been even greater as the silver material would have dispersed the light to a greater extent than the dye material.

The filters used were found to be quite adequate, especially the red. Had a red filter of a lower transmittance value been used, there would not have been sufficient radiation to permit the instrument to function correctly. That is to say, that there would not have been enough energy to excite the photomultiplier enough to bring it to a 'zero' position (100% transmittance).

As projected density is a new specification, it would be of interest to compare it to diffuse and specular density. The Callier Q factor is a factor that relates diffuse density to specular density, under specified conditions.[1] If measurements were made and a comparison evaluated between projected density and either diffuse or specular density, it would be possible to determine how projected density compares to other types of density. It would also be of interest to see how this value compares to Callier's Q factor. Since Callier's Q factor is based on a silver system, the results of this experiment can not be used, therefore, further testing would be necessary.

For this experiment, a prototype instrument was not completed as planned, therefore, the secondary aims as discussed in the Introduction could not be fully tested. Enough information was gained, however, to permit finalized specifications for a prototype instrument. These are contained in figure 5.

In summation, this author believes that the project was one of considerable wealth to him as a learning experience. The fact that a one-of-a-kind instrument was built and was found to function correctly indicates that the project was a success.

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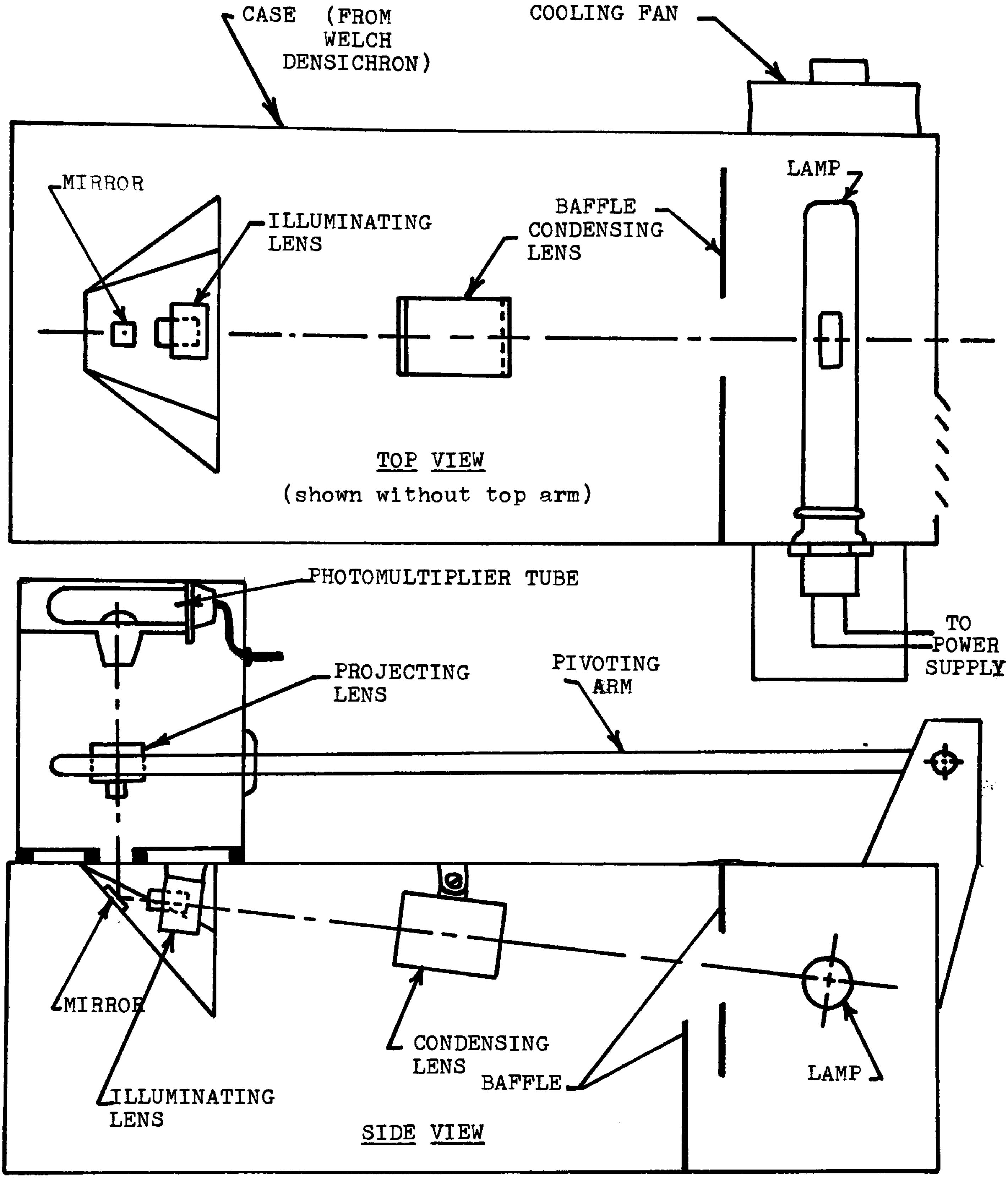
[1] C.E.K. Mees, T.H. James, ed., The Theory of the Photographic Process, (New York, 1967), p. 425.



Scale: 3/8" = 1"

Figure 5

APPENDIX

APPENDIX A

American National Standard
Conditions for Transmission Measurements Pertaining to Projection

PH2-28/27

Draft

American National Standard
Conditions for Transmission Measurements Pertaining to Projection

(Optical Density)

ANSI Subcommittee PH2-28

Sponsor

Photographic Standards Board

Fifth Draft

November 1969

American National Standard Conditions for Transmission Measurements Pertaining to Projection

Introduction

Motion pictures and slides are most often viewed by projection. Projection equipment utilizing condensers is commonly used to print and enlarge photographs. A given area on a negative affects the amount of light going from the lamp to the printing paper by a different factor in such projection printing than it does in contact printing. In spite of these differences, there has not been, heretofore, an American National Standard to define projection density as there has been to define diffuse density, which pertains to contact printers and diffuse illuminators.

This standard conforms to ANS1 Standard PH2.XX-____ "American National Standard Terms, Symbols, and Notation for Optical Transmission and Reflection Measurements."

The conditions defined in this standard are intended to simulate the optical conditions affecting the transmission characteristics of a small area on a negative or transparency at the center of the frame of a typical projection system utilizing condensers. The small area under consideration may be considered defined by a small opening, known as the sampling aperture, in an otherwise opaque sheet in the frame.

Only the flux that is transmitted by the same sample area of the film and reaches the projection lens is involved in forming the projected image. The modulation factor is measured and expressed as a ratio of this flux to some reference flux. The reference flux could be:

(1) the total flux incident on the sampling aperture,

(2) the flux reaching the projection lens from the sampling aperture when there is no film in the aperture, or

(3) the flux reaching the projection lens from the sampling aperture when there is some reference standard film, such as unexposed processed film, in the aperture.

The first case would be a measurement of transmittance, which is little used in practical photography and is not treated in this standard. The other two cases, of practical interest because they are directly related to characteristics of the projected image, are treated in this standard, as are the optical densities, the negative logarithms to the base ten of the corresponding ratios.

The measured optical density depends on the angle subtended by the projection lens, which is usually specified in terms of the f-number. This standard specifies two types of projection density, corresponding to f/4.5 and f/1.6 projection lenses. The f/4.5 type is typical of microfilm readers and the f/1.6 type is typical of motion picture projectors.

1. Scope

This standard defines several transmission characteristics of thin sheet materials to be used in projection equipment utilizing condensers, for either viewing or printing, and specifies conditions for their measurement.

2. Geometric Conditions

2.1 Sampling Aperture

The area of the sample being measured shall be defined by a circular sampling aperture in a plane (the x,y plane) normal to the optical axis (the z axis), centered on the optical axis at the point 0, and having a diameter not greater than one-tenth the diameter of either the illuminating or projecting lens.

Ideally, the incident flux should be uniformly distributed over the area of the sampling aperture. When the sampling aperture is scanned with a photometer having essentially uniform angular response throughout an acceptance angle of at least 20° and essentially uniform response over a circular sensing area with a diameter one-fourth that of the sampling aperture, the flux measured at any place on the aperture shall be within 10 percent of the maximum value.

2.2 Influx Geometry

2.2.1 f/4.5 Type

The angular distribution of incident radiance, with respect to point 0 should be uniform at all angles within a right circular cone, with its axis on the optical axis (z axis) and its apex at point 0, having a half-angle between 6.2° and 6.5°. This angular distribution corresponds to an f-number between 4.4 and 4.6. The nominal half-angle is 6.3°.

2.2.2 f/1.6 Type

The angular distribution of incident radiance, with respect to point 0 should be uniform at all angles within a right circular cone, with its axis on the optical axis (z axis) and its apex at point 0, and having a half-angle between 16.4° and 18.4°. This angular distribution corresponds to an f-number between 1.5 and 1.7. The nominal half-angle is 17.3°.

2.2.3 Uniformity of Influx Geometry

When the angular distribution of radiance is scanned by a photometer with essentially uniform angular response over a conic distribution, having a half-angle of 2°, the radiance for any direction within the influx cone shall be within 10 percent of the maximum. There should be no detectible flux from directions outside the influx cone. The radiance, scanned with the 2° cone, at every direction outside the influx cone shall be less than 2 percent of the maximum within the influx cone.

2.3 Efflux Geometry

2.3.1 f/4.5 Type

The angular distribution of the sensitivity of the receiver (including the effects of any filters, integrating sphere, or other optical components), with respect to point 0, should be uniform at all angles within a right circular cone, with its axis on the optical axis (z axis) and its apex at point 0, and having a half-angle between 6.2° and 6.5°. This angular distribution corresponds to an f-number between 4.4 and 4.6.

2.3.2 f/1.6 Type

The angular distribution of the sensitivity of the receiver (including the effects of any filters, integrating sphere, or other optical components), with respect to point 0, should be uniform at all angles within a right circular cone, with its axis on the optical axis (z axis) and its apex at point 0, and having a half-angle between 16.4° and 18.4°. This angular distribution corresponds to an f-number between 1.5 and 1.7.

2.3.3 Uniformity of Efflux Geometry

When the angular distribution of sensitivity is scanned by a small solid angle defined by a conic distribution having a half-angle of 2°, for any direction within the efflux cone, it shall be within 10 percent of the maximum.

3. Spectral Conditions

3.1 Influx Spectrum

The relative spectral distribution of the incident flux shall be proportional to that of a tungsten lamp operated at a color temperature of 3000K. This distribution is given in Table 1 under the heading "3000K".

3.2 Visual ~~Efflux~~ Spectral Sensitivity

For visual applications, the spectral distribution of the sensitivity of the receiver (including the effects of any filters, integrating sphere, or other optical components) shall be proportional to the photopic spectral luminous efficiency. This distribution is given in Table 1 under the heading V(λ).

3.3 Silver Halide Printing ~~Efflux~~ Spectral Sensitivity

For applications involving projection printing on commonly used silver halide photographic materials, the spectral distribution of the sensitivity of the receiver (including the effects of any filters, integrating sphere, or other optical components) shall be proportional to the distribution given in Table 1 under the heading "$P_2(\lambda)$".

3.4 Tolerances on Spectral Conditions

The tolerances on the spectral characteristics of the system shall be such that the measured quantities will not differ significantly from those which would be obtained if the specified spectral conditions were exactly met. If the samples to be measured do not fluoresce, phosphoresce, or otherwise radiate, the influx spectrum and spectral sensitivity can be allowed to depart from the prescribed relative distributions providing their product at each wavelength is proportional to the product of the prescribed distributions.

4. American National Standard Projection Transmittance Factors

4.1 American National Standard Projection Transmittance Factor

The ratio Φ_t/Φ_j, where Φ_t is the flux transmitted by the sample and evaluated by the receiver and Φ_j is the flux evaluated by the receiver when there is no sample in the sampling aperture, when the geometric conditions of Section 2 are satisfied. Any spectral conditions may be employed.

4.2 American National Standard Projection Relative Transmittance Factor

The ratio Φ_t/Φ_{ts}, where Φ_t is the flux transmitted by the sample and evaluated by the receiver, Φ_{ts} is the flux transmitted by a reference standard, such as a piece of film base or a film having only base and fog density, and evaluated by the receiver, when the geometric conditions of Section 2 are satisfied. Any spectral conditions may be employed.

4.3 Geometric Types

Two geometric types of projection transmittance factors are specified by the nominal f-number, f/4.5 denoting the geometric conditions of Sections 2.2.1, 2.2.3, 2.3.1, and 2.3.3 and f/1.6 denoting the geometric conditions of Sections 2.2.2, 2.2.3, 2.3.2, and 2.3.3.

4.4 Spectral Types

Two spectral types of projection transmittance factors are specified, "Visual" denoting the spectral conditions of Sections 3.1 and 3.2 and "Printing" denoting the spectral conditions of Sections 3.1 and 3.2.

4.5 Terms and Notation

The various American National Standard Projection Transmittance factors are assigned names and notations as follows:

American National Standard Projection Transmittance Factor,

$T(\kappa_1; s : \kappa_t; s')$

American National Projection Relative Transmittance Factor,

$T_r(\kappa_1; s : \kappa_t; s'/r)$

American National Standard f/4.5 Projection Transmittance Factor,

$T(6.3°; s : 6.3°; s')$

American National Standard f/1.6 Projection Transmittance Factor,

$T(17.3°; s : 17.3°; s')$

American National Standard f/4.5 Projection Visual Transmittance Factor,

$T(6.3°; 3000K: 6.3°; V)$

American National Standard f/4.5 Projection Printing Transmittance Factor, $T(6.3°; 3000K : 6.3°; P_2)$

American National Standard f/1.6 Projection Visual Transmittance Factor, $T(17.3°; 3000K : 17.3°; V)$

American National Standard f/1.6 Projection Printing Transmittance Factor, $T(17.3°; 3000K : 17.3°; P_2)$

5. American National Standard Projection Transmittance Densities

Transmission density D_T is defined as the negative logarithm to base ten of transmittance factor T:

$$D_T = -\log_{10} T.$$

There is an American National Standard Projection Transmittance Density corresponding to each transmittance factor named in Section 4.5. They are given names and notations as in the following examples: American National Standard f/4.5 Projection Visual Transmission Density, $D_T\ (6.3°; 3000K : 6.3°; V)$ and American National Standard f/1.6 Projection Printing Relative Transmission Density, $D_{Tr}\ (17.3°; 3000K : 17.3°; P_2/bf)$.

Table 1. Relative Spectral Distributions

λ in nm	3000 K	V(λ)	P(λ)*	λ in nm	3000 K	V(λ)
340	5		0.1	560	100	99.5
350	6		8.7	570	106	95.2
360	8		59	580	113	87.0
370	10		87	590	119	75.7
380	12	0.004	100	600	125	63.1
390	15	0.012	100	610	131	50.3
400	18	0.04	95.5	620	138	38.1
410	21	0.12	87	630	144	26.5
420	24	0.40	79	640	149	17.5
430	28	1.16	69	650	155	10.7
440	32	2.3	58	660	161	6.1
450	37	3.8	46	670	166	3.2
460	42	6.0	33	680	172	1.7
470	47	9.1	22	690	177	0.82
480	52	13.9	13.5	700	182	0.41
490	57	20.8	7.1	710	186	0.21
500	63	32.3	2.8	720	191	0.105
510	69	50.3	0.65	730	195	0.052
520	75	71.0	0.15	740	199	0.025
530	81	86.2	0.035	750	203	0.012
540	87	95.4	0.001	760	207	0.006
550	94	99.5				

*The product of an average of the relative spectral sensitivities of commonly used photographic printing materials and the transmission of an ultraviolet absorbing filter with a sharp cutoff at 360 nm (Corning No. 738, Wratten No. 1, or equivalent) to avoid uncertainties of transmission of optical components and the known high transmittance of silver deposits at shorter wavelengths.

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